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POLLUTION OF THE YELLOWSTONE RIVER AS RELATED TO TASTE AND ODOR PROBLEMS IN MUNICIPAL WATER SUPPLIES IN MONTANA AND NORTH DAKOTA

Public Health Service
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POLLUTION OF THE YELLOWSTONE RIVER

AS RELATED TO

TASTE AND ODOR PROBLEMS IN MUNICIPAL WATER SUPPLIES

IN MONTANA AND NORTH DAKOTA

A COOPERATIVE FIELD INVESTIGATION

UNDERTAKEN JOINTLY BY

STATE BOARD OF HEALTH
HELENA, MONTANA

STATE DEPARTMENT OF HEALTH
BISMARCK, NORTH DAKOTA

AND

DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE
U. S. PUBLIC HEALTH SERVICE
WATER SUPPLY AND WATER POLLUTION CONTROL ACTIVITIES
REGION VI

NOVEMBER 7-13, 1955

JULY 1956

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SUMMARY

Field survey and laboratory results demonstrate heavy pollution and ideal conditions for development of tastes and odors in the Yellowstone and Big Horn Rivers. No taste and odor problem materialized during the period of study that could not be overcome by normal water treatment practices, but high potential was clearly apparent.

A summation of major sources of pollution discharged to the various reaches of the stream is shown in Tables 1 and 2. Laboratory data from stream and industrial waste studies are summarized in Tables 3 and 4. Total organic matter, as established by suspended solids; chemical oxygen demand, and 5-day 20° C. B.O.D., demonstrates heavy pollution of the stream.

Copper, lead and chromium are also present in industrial waste discharges. Amounts do not appear significant, but their presence warrants consideration. Each is toxic in small amounts, with increased emphasis through synergistic action or antagonistic effects on natural biological processes in the stream.

The quantity of phenols entering the river is large. Minute amounts of these materials impart objectionable tastes and odors to water supplies. The phenol producing industries were not all operating at average production rates, and some units were out of operation. The maximum quantity discharged thus could be much greater than recorded during the study. Phenols and related compounds are a critical waste constituent relative to development of tastes and odors. Organic wastes from miscellaneous sources contribute significantly to the over-all problem.

Pollution of the river is so excessive that an immediate and aggressive program of abatement is fully warranted. Adequate waste control can be provided through methods already demonstrated to be wholly effective.

RECOMMENDATIONS

To provide reasonable protection against recurrence of objectionable taste and odor problems at downstream water plants, it is recommended that:

1. All industries undertake an aggressive program to minimize waste losses to sewers and drains by: changes in industrial processes; reclamation of materials now wasted; close operating control to prevent excessive discharges, accidental or otherwise; treatment of residual wastes; and constant monitoring to maintain minimum discharge of pollutional materials.

2. The Underpass Drain be relaid of durable materials and constructed to exclude infiltration of oil bearing ground water. Reportedly construction of this improvement has been completed.

3. Each oil refinery:

   (a) Provide virtual elimination of phenols and related compounds, toxic materials, free and emulsified oils, and floating and settleable solids from its waste discharges.

   (b) Neutralize all caustic or acidic wastes prior to discharge to surface waters.

   (c) Surface and supervise loading areas and provide treatment or retention for all wastes and spills from loading operations.

   (d) Store and handle toxic or other pollutional materials, to be disposed of other than to sewer, so that leaching into underground or surface water be precluded.

4. Each sugar refinery effect virtual elimination of all settleable and floatable solids, and reduce 5-day 20° C. B.O.D. to not more than 8# per ton of beets sliced.

5. Each meat packing installation provide effective grease removal, effectively screen all wastes except sanitary sewage, and make appropriate arrangements as necessary for discharge of residual plant wastes to municipal sewers.

6. The City of Laurel repair breaks in its sewer system to eliminate extraneous unpolluted waters now entering the system.

7. The Railroad at Laurel effect waste reduction either by discharge into municipal sewers or by the installation of efficient treatment facilities for its own use.

8. The Cities of Miles City, Glendive, and Sidney provide effective primary treatment of their sewered wastes.

9. The Cities of Hysham, Forsyth and Hardin enlarge or replace existing facilities to provide efficient treatment.

10. Waste treatment works outlets be extended as necessary to discharge directly into the main channel of the river in order to take maximum advantage of dilution and to prevent accumulation of waste material in secondary river channels.

11. Oil producing fields in the Yellowstone basin be thoroughly investigated and appropriate controls employed to assure that each installation does not constitute a source, or potential source, of pollution from oil and related materials.

12. Each industry and community not now providing adequate control of pollution, prepare a comprehensive plan of pollution control, including a time schedule, and present it to the Montana State Board of Health for formal review and approval or comment. Every effort should be made to advance the program as rapidly as possible in order to reduce the possibilities of taste and odor development.

13. Cooperation and assistance of the Department of Health of Wyoming be sought to obtain treatment of municipal wastes and industrial pollution entering the Big Horn River in Wyoming.

INTRODUCTION

The lower Yellowstone River has developed intermittent conditions, usually in fall or winter, resulting in severe taste and odor problems in municipal water supplies. Difficulties have occurred at Hardin on the Big Horn River, and at Forsyth, Miles City, and Glendive, Montana, on the Yellowstone. Less severe problems have been experienced at Billings. Williston, North Dakota, situated on the Missouri downstream from the Yellowstone, has also encountered difficulties attributed to the Yellowstone. Severity of the problem has varied from conditions amenable to control by modified water treatment procedures to situations beyond the scope of available treatment facilities.

Surveys designed to inquire into the nature of stream conditions, discharge, pollution, plankton density, etc., promoting unpalatable water quality were conducted cooperatively by the Montana State Board of Health and the U. S. Public Health Service in August and September 1952. No taste and odor problems occurred that year, but the studies indicated several factors and combinations thereof that could periodically cause trouble. An acute taste and odor problem occurred in 1954 and extended to Williston, North Dakota, on the Missouri River. Complaints arising from this occurrence indicated the necessity of another survey to include quantitative measurement of various waste components discharged to affected streams, more extensive laboratory work, and carbon filter studies. Therefore, a cooperative study involving the State Health Departments of Montana and North Dakota, and the U. S. Public Health Service was initiated on November 5, 1955.

PROCEDURES

The study was concerned with measurement of various waste components and evaluation of their effects in the lower 360 miles of the Yellowstone and the final 41 miles of the Big Horn River. Engineering evaluations of both the volume and characteristics of the wastes were made from detailed studies of the various processes in all industries contributing appreciable amounts of industrial wastes to both rivers. These were later followed up with actual measurement and analytical

determinations on the plant effluents to determine actual contributions. Volume and strength of industrial and municipal wastes were measured by compositing samples according to flow at two-hour intervals over 24-hour periods. Industrial wastes studies included the discharges of three oil refineries, three sugar refineries, a railroad maintenance outlet, a highway underpass drain, and two meat packing plants. Composites of municipal waste discharges were made at Billings and Laurel. Three grab samples were collected on alternate days from each stream station. A 24-hour composite for chromium was obtained at the Laurel waterworks intake. Station locations are shown in Plate 1 and analytical data appear in Tables 1, 2 and 3.

Limnological studies were conducted August 24-26 and November 6-13, 1955. The August sampling program was limited to bottom flora and fauna, plankton, temperature and turbidity. In November the above schedule was accompanied by field analyses for pH, alkalinity, oxygen, ammonia and nitrite nitrogen, and phosphate.

Carbon filters were installed at Laurel, Billings and Forsyth. Those at Billings and at Forsyth accumulated materials contained in river water before and during the sugar beet campaign. A third filter was used at Forsyth after sugar refinery wastes were discontinued. The first filter installed at Laurel was influenced by local wastes brought to the water intake by partial damming as a result of local construction activities. This condition was remedied and a second filter run was assumed representative of normal stream condition. A separate filter was dosed with sugar beet wastes.

ACKNOWLEDGMENTS

The Montana State Board of Health conducted analyses for phenols, copper, and lead, assisted in the sampling program, and supervised installation and shipment of carbon filters. The North Dakota State Department of Health assisted in sample collection. The U. S. Public Health Service assumed over-all coordination of the study, conducted industrial evaluations, provided all analyses, except those mentioned above, evaluated stream conditions, and developed a final report, following its review in draft form by the State Health Departments of Montana and North Dakota. Stream flow data were furnished by the U. S. Geological Survey. The city of Billings provided laboratory facilities, parking space for a mobile laboratory, and collected some samples. The Carter Oil Company aided sample collection. Carbon filters were installed and serviced by water operators at Laurel, Billings, and Forsyth. Carbon filter analyses were conducted by the Organic Contaminants Unit, Robert A. Taft Sanitary Engineering Center. Industrial waste evaluations and reports thereon were completed by the Industrial Waste Unit, Robert A. Taft Sanitary Engineering Center.

The cooperation of all individuals, which involved long hours of duty and required aggressive interest, was excellent and is gratefully acknowledged.

DESCRIPTION

The Yellowstone River (Plate 1) enters the investigated reach as a succession of pools and rapids that gradually merge into a uniform stream below the mouth of the Big Horn. Bottoms in upstream reaches are mainly composed of rock and gravel which are increasingly overlaid by sand and silt in lower stretches. At discharges ranging from 2,000 to 5,000 c.f.s. the river is normally quite clear, except below waste outfalls, down to the mouth of the Big Horn. Turbidity contributed by the Big Horn varies annually thus the Yellowstone is frequently clear all the way down to a region of intensive irrigation above Sidney. During both periods of study in 1955 it was noticeably turbid in all stretches below the Big Horn. Stream slope is about 7.2 feet per mile over the entire distance.

POLLUTION DISCHARGED

Tables 1 and 2 summarize municipal and industrial waste discharges in the area under investigation. At Laurel, Montana, the Yellowstone receives 5 waste outfalls, 3 carrying oil refinery wastes, one discharging from a railroad shop, and one from the city's primary sewage treatment plant. The oil refinery has only two waste lines but oil contamination of the ground effects a tile drain (Highway Underpass Drain) passing near the plant. This drain, reportedly of open joint construction, empties into the river below the Laurel water plant, often bringing in oil, and continually adding to whitish sulfur bottom deposits. Contributed oil often forms extensive films on the river surface and oil deposits occur along the banks and upon stranded debris. Refinery wastes are discharged directly to two ditches. The upstream ditch, which carries the greater portion of the oil wastes, splits near its lower end and sends part of its discharge directly to the river and the rest to a ditch that receives the lower oil waste line and effluent from the sewage treatment plant. The latter ditch and wastes from the railroad shops enter an isolated channel or slough formed by a chain of three islands near the left riverbank. The slough receives discharge from the main channel above the upper island only when river stages are higher than those noted in November. However, flow from river to slough occurred between the first and second, and second and third islands. The slough flows back into the main channel below the third island. Behind the first island the slough was a quiescent body of dark colored water containing oil and biological growths. The slough became a small rapids, 10 feet wide and 6 inches deep, near the lower end of the first island, and rocks situated therein bore luxuriant algal growths. Sulfur deposits cover a part of the river bottom in that locality, and oil slicks often spread out over the main path of flow.

At Billings the river receives: (1) Yegen Ditch, into which are discharged wastes from two meat packing houses, an oil refinery, and a sugar beet plant; (2) the effluent from the city primary sewage treatment plant; and (3) wastes from another oil refinery. Pollutants leaving Yegen Citch flow along the west bank of the river. Sludge beds extend

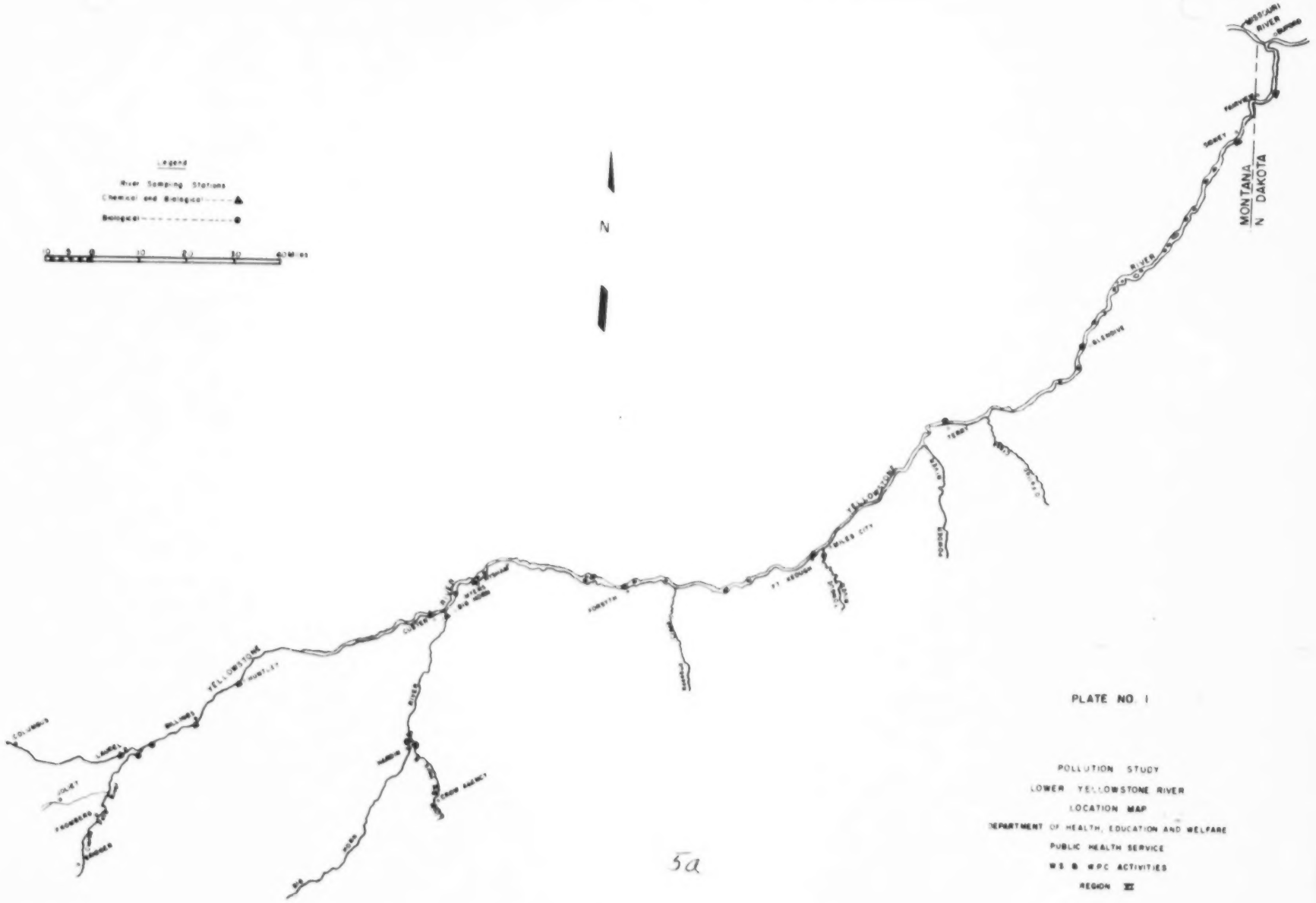

PLATE NO. 1

POLLUTION STUDY
LOWER YELLOWSTONE RIVER
LOCATION MAP
DEPARTMENT OF HEALTH, EDUCATION AND WELFARE
PUBLIC HEALTH SERVICE
W S & W P C ACTIVITIES
REGION VI

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Table 1. Yellowstone River Study - November 1955 - Daily Municipal Sewage Discharges

Stream and Municipality	Approx. miles above mouth: Yellowstone River	Approx. miles above mouth: Tributary	1950 Population	Population Equivalent (B.O.D.) Untreated Wastes[1]	Treatment Provided	To Watercourse: Phenol Pounds	To Watercourse: MGD	To Watercourse: B.O.D. Pounds	To Watercourse: Population Equiv. B.O.D.	Project Needs
Yellowstone River										
Laurel, Mont.	370		3,663	4,000	Primary	.45	.52	268	1,608	None
Billings, Mont.	346		31,834	30,000	Primary	1.75	7.8	2,745	16,470	None
Hysham,* Mont.	260		410	275	Primary	-	-	42	250	E
Forsyth,* Mont.	230.8		1,906	2,000	Primary	-	-	267	1,600	E
Miles City,* Mont.	180.8		9,243	7,235	None	-	-	1,206	7,236	NP
Terry,* Mont.	134.5		1,191	500	Primary	-	-	75	450	None
Glendive,* Mont.	92.1		5,254	5,132	None	-	-	855	5,132	NP
Sidney,* Mont.	30.2		3,987	3,036	None	-	-	506	3,036	NP
Fairview,* Mont.	20		942	1,200	Primary	-	-	160	960	None
Big Horn River	279.4									
Hardin,* Mont.		40.5	2,306	1,800	Primary	-	-	240	1,440	None
TOTAL			60,736	55,178				6,364	38,182	

[1] Includes organic industrial wastes discharging to municipal systesm.
*Quantities and strengths estimated.
E - Enlargement of existing plant.
NP - New primary plant.

Table 2. Yellowstone River Study, November 7-13, 1955 - Wastes Discharged by Areas

	AREAS			
	Laurel	Billings	Hardin	Sidney
Volume MGD	4.05	53.20	4.6	7.2
Biochemical Oxygen Demand 5-day 20° C.	1,559	100,228	23,850	26,600
Suspended Solids - Pounds	1,570	615,137	85,500	216,600
Phenols - Pounds	22.0	262.0	0	0.2

about 100 yards below the mouth of the ditch. Gas bubbles are evolved from the deposits. The ditch discharge was very turbid in November, frequently contained oil and blood, and floating solids tended to accumulate near its mouth. Blood and bits of animal tissue are often present in water passing the bridge on U. S. Highway 87. Dead fish are common in this region. Below this bridge the sewage plant outfall introduces grayish primary effluent, and the lower oil refinery discharges a greenish liquid. Upstream from the lower oil refinery outfall whitish sulfur deposits covered coarse algal filaments on the bottom. Fragments of these growths collected on screens at the oil refinery water intake and necessitated frequent cleaning.

Sugar beet wastes from the Sidney factory enter an open ditch at the east edge of the plant. This ditch flows southeast to join irrigation drain ditches that flow for some distance before joining the Yellowstone. The Hardin beet plant discharges wastes into a channel of the Big Horn River.

Oil wastes are at times evident over long stretches of the river. In November the odor of refinery wastes was apparent at all stations from Billings to Forsyth. In August no such odors were evident at any station on the river. No samples were taken immediately below waste outfalls at that time.

STREAM DISCHARGE

Yellowstone discharge at Billings, Montana, varied from 3,400 to 3,550 cubic feet per second during the sampling period. Five-year minimum expected flows are 2,274 c.f.s. in summer and 1,587 c.f.s. in winter. At Miles City, Montana, flow varied from 5,950 to 6,690 c.f.s. There five-year minimum expected flows are predicted at 3,693 c.f.s. in summer and 2,487 c.f.s. in winter. At Sidney, Montana, minimum flows expected to occur once in five years are lower than those predicted at Miles City. Twenty daily flow records during November and December 1955 show discharges from 1,080 to 4,690 c.f.s. at Billings.

Flow in the Big Horn during the sampling period varied from 2,370 to 2,660 c.f.s. at two sampling stations. The five-year minimum expected flows at the gauging station near St. Xavier, Montana, are 1,350 c.f.s. and 1,124 c.f.s. for summer and winter, respectively.

It is therefore evident that the study was made during river stages averaging well above critical levels expected to occur as frequently as once in five years.

CHEMICAL FEATURES

A compilation of stream data is set forth in Tables 3 and 4. The days of sample collection are before and following the periods of compositing of the waste sources and therefore should be representative of the effects of the same wastes.

Table 7. Yellowstone River Study - November 1955 - Laboratory Data from Stream Samples

Station	Date Nov.	Time	pH Field	pH Lab.	°C Temperature	Dissolved Oxygen ppm.	Oxygen Consumed ppm.	5-day 20° C. Biochemical Oxygen Demand ppm.	5-day 20° C. Biochemical Oxygen Demand Pounds	Ratio B.O.D. to O.C. %	Copper ppm.	Copper Pounds	Phenol ppb.	Phenol Pounds	Lead ppm.	Lead Pounds	Time of River Gauge Reading	Discharge* c.f.s.	Velocity* ft. per sec.	River Mile	Time of Flow Billings to	Time of Flow Hardin to
Laurel - Water Works Intake	7	11:10 A.	7.6	8.1	4.0	12.50	14.9	1.0	16,130	6.7	.01	161.3	1.0	16.1	0.3			3,000				
	9	12:00 N.	8.0	7.9	6.0	12.05	7.9	0.7	10,780	18			0	-				2,860				
	12	10:30 A.	8.1	7.8	2.0	12.55	7.8	0.9		11.6			-					-				
Billings - Water Works Intake	7	1:50 P.	7.7	8.2	5.0	13.30	19.6	1.7	32,500	8.7	.01	191	3.0	57.4	0.01	191	10:15 A.	3,550	2.3	346.0		
	9	4:30 P.	7.7	8.0	5.0	11.65	11.7	1.1	20,060	9.4			5.0	91.5			4:00 P.	3,400	2.2			
	11	4:05 P.	7.8	8.2	2.0	12.65	15.7	0.7	13,400	4.5			0	0.0			4:05 P.	3,550	2.3			
Huntley - Bridge Hiway 10	7	3:20 P.	8.1	8.0	5.0	9.40	23.1	4.6	88,100	19.6	.01	191	9.0	172.0	0.00	0				334.7	0.3 days	
	9	11:00 A.	7.7	7.3	4.0	10.05	27..	6.1	111,800	22.2			12.0	220.0								
	11	12:45 P.	7.9	7.8	2.0	10.90	23..	4.5	86,200	19.1			35.0	670.0								
Custer - Bridge State Hiway 47	7	2:00 P.	8.1	8.1	5.0	12.30	13.7	3.0	57,400	21.9	.005	96	1.5	28.7	0.01	191						
	9	1:25 P.	8.2	7.9	5.0	11.35	17.6	2.5	45,800	14.2			1.5	27.4								
	11	9:50 A.	8.1	7.9	3.0	7.40	17.6	2.3	44,000	13.1			6.0	115.0								
Big Horn enters Yellowstone R. between Custer and Myers																				294.4	1.73 days	1.0 days
Myers - Bridge State Hiway	7	12:10 P.	7.4	8.0	3.5	11.10	29.4	2.2	75,300	7.5	.01	340	1.5	51.0	0.02	680		6,320c				
	9	12:15 P.	8.1	7.8	4.0	10.85	19.6	3.5	110,500	17.9			1.5	47.0				5,950c				
	11	11:00 A.	7.9	7.9	2.0	8.35	19.6	3.2	107,200	16.3			5.0	168.0				6,230c				
Miles City - Water Works Intake	7		7.4	8.3	3.2	12.60	21.5	1.9	67,500	8.8			1.5	53.0			2:00 P.	6,590	2.35			
	9			7.9		12.05	13.7	4.9	176,500	35.8			0	0			12:00 N.	6,690	2.35	178.5	4.2 days	3.6 days
	11	11:50 A.	7.7	8.0	3.0	11.80	19.6	1.5	48,100	7.7			2.0	66.0			12:00 N.	5,950	2.35			
Sidney - Bridge State Hiway 235	7		7.6	8.1	0.5	13.10	16.2	2.2	68,500	.3			3.0	92.8				5,770		30.9	8.2 days	7.5 days
	9			8.0		12.45	15.7	3.2	75,700	20.4			1.5	35.8				4,440				
	11	5:45 A.	7.8	8.0	1.0	11.65	25.4	1.0	34,600	3.9			0	0				6,440				
Cartwright - N.D. State Hiway 23	7	6:45 A.	7..	8.4	0.5	13.10	43.0	3.4	105,500	7.9			3.0	92.8								
	9			8.0		12.15	15.7	3.2	75,700	20.4			4.0	73.6								
	11	6:45 A.	8.0	7.9	1.0	11.90	29.4	4.0	138,400	13.6			0	0								
Hardin - Beet Sugar Plant H2O Intake Big Horn River	7	10:10 A.	7.5	7.9	3.5	11.75	33.3	2.6	37,200	7.8	.00	0	1.5	22.0	0.02	287	10:10 A.	2,660	2.5			
	9	2:30 P.	8.1	8.1	5.0	11.75	19.6	2.8	37,100	14.3			0	0			2:30 P.	2,660	2.5			
	11	5:30 A.	8.3	8.3	1.0	8.55	25.4	2.6	33,600	10.2			6.0	78.0			5:30 A.	2,600	2.5			
Big Horn - Bridge Hiway 10 Big Horn River	7	1:10 P.	7.8	8.1	4.0	11.40	31.3	4.8	63,600	15.3	.015	200	1.5	20.0	0.04	531	1:10 P.	2,660	2.5	Little B.H. 40 mi.		
	9	12:50 P.	8.1	8.2	5.0	10.60	25.4	4.0	53,100	15.7			0	0			12:50 P.	2,460	2.5			
	11	10:20 A.	8.0	7.9	2.0	11.25	23.5	1.9	24,210	8.1			4.0	51.0			10:20 A.	2,370	2.5			

*Information obtained from U.S.G.S.

c - Calculated. Yellowstone + Big Horn.

Table 4. Yellowstone River Study - Individual Field Analyses

Station	Temperature C° Aug.	Temperature C° Nov.	Turbidity ppm. Aug.	Turbidity ppm. Nov.	November only: pH	CO_3 Alk. ppm.	HCO_3 Alk. ppm.	Oxygen % Sat.	NH_3 ppm.	NO_2 ppm.	PO_4 ppm.
Yellowstone R. above Laurel	19.5	4	<20	<20	8.1	10	102	103.2	0.1	0	0
Yellowstone R. 1 mi. below Laurel		6.5		<35	8.0	2	128		1.2	0.02	<2
Clarks Fork R. near mouth	20	2.5	<20	64	8.2	14	186	92.8	0.15	0	0
Yellowstone R. 3 mi. below Laurel		5		<35	8.0	4	116	92	0.1	0.01	0
Yellowstone R. below Yegen Ditch		13.5		230	8.4	-	<284	43	2.4	0.07	0
Yellowstone R. Hwy 87 Bridge below Billings		6	<20	<35	8.2	12	126	101	0.1	0	0
Yellowstone R. near Huntley	24	5	<20	42	8.0	6	140	84.2	0.1	0.005	0
Yellowstone R. near Custer	25	1	<20	32	8.2	8	138	93.5	0.1	0.005	0
Big Horn R. near Hardin	25	1.5	390	192	8.2	16	191	89.2	0.01	0.005	0
Little Big Horn near mouth		1.5		<35	8.2	14	201	96.0	0.1	0	0
Big Horn R. near Big Horn	25	2	480	131	8.2	16	191	95.9	0.1	0.005	0
Yellowstone R. at Myers	25	0	240	137	8.2	8	170			0.005	
Yellowstone R. at Forsyth	26	0	140	77	8.2	10	163	90.5	0.1	0.005	0
Yellowstone R. at Ft. Keough	25	0	160	72	8.2	10	175	89.8	0.1	0.01	0
Tongue R. near mouth		0		102	8.2	12	261	89.8	0.1	0.0	0
Yellowstone R. near Terry		0		60	8.2	10	177	95.4	0.1	0.005	0
Yellowstone R. at Glendive	25	0	1,000	135	8.2	10	183	94.8	0.1	0.005	0
Yellowstone R. above Sidney	25	0	220	105	8.2	12	191	94.2	0.1	0.005	0
Yellowstone R. near Cartwright	25	0	150	84	8.2	12	196	94.2	0.1	0.005	0
In Yegen's Ditch		16						18.1			

The pH determinations of all sampling stations were well within a normal range and indicate insufficient variation in the continuous discharge of pollution to markedly increase or suppress the alkaline or acidic balance in river water. The range noted is satisfactory for natural stream purification processes.

Water temperatures varied from 6.5° C. to just above freezing. Temperatures as low as those in November are antagonistic to rapid oxidation of pollutants amenable to biochemical action. A reduced rate of biochemical oxidation permits pollution to carry farther downstream and exert deleterious effects over a greater distance in the stream under similar flow conditions. At the same time, reduced exertion of biochemical oxygen demand has less effect on the dissolved oxygen level of the river water, and permits increased replacement of dissolved oxygen by reaeration. Althouth this is favorable for maintaining oxygen levels, it is unfavorable for the desired rapid rate of oxidation of taste and odor producing constituents.

Dissolved oxygen in both streams approached or exceeded saturation in most instances. A lowering of dissolved oxygen at Huntley on November 7, at Custer and Myers on the 11th and above the industrial waste outlet at Hardin on the Big Horn on the 11th, were the most pronounced. However, in these instances, dissolved oxygen was well above the critical levels for sustaining fish and other aquatic life.

Oxygen consumed and 5-day 20° C. biochemical oxygen demand values were low in parts per million, eliminating them as critical items in taste and odor development except for possible synergism.

Turbidity maximums were considerably greater in August although not confined to the same reaches of the stream as in November. The known contribution of turbidity by the Big Horn River and subsequent dilution by the Yellowstone was evident. During November turbidity existed upstream in the Yellowstone above the confluence of the Big Horn, apparently from operations of a beet sugar refinery.

Alkalinities, both carbonate and bicarbonate, were in normal concentrations. Some localized variations were shown by the increase in carbonates due to photosynthesis and higher concentrations of bicarbonates from waste discharges.

Ammonia and nitrite followed the usual pattern of the nitrogen cycle. In most instances the presence and concentration followed the entrance and purification pattern of wastes.

The trend of phosphate changed from its presence at all stations except Miles City in 1952 (and consequently considered to be a natural compound in the river) to its complete absence in 1955 except at the outlet to the slough impounding wastes below Laurel. Its occurrence or non-occurrence at low levels is of importance from the standpoint of nutrients for algae metabolism.

Copper was found at all stations for which determinations were made except in the Big Horn River above the industrial waste outlet. Lead was found at all stations analyzed except at Huntley Bridge on Highway 10 below Billings. Chromium determinations were made at only a few selected points. These metals are important in water pollution control due to their toxicity in relative minute quantities. Individually they may inhibit natural stream purification processes or actually kill off living organisms in the stream. In combination with each other they may be more toxic than the additive effect of each. Quantities noted are merely indicative of their presence and substantiate the need for monitoring and control of the sources.

Phenols from the oil refining industry have been under surveillance in the Yellowstone River for some period of time by the Montana State Board of Health. Phenolic compounds at very low concentrations are known to develop tastes and odors in water supplies. The highest and most consistent concentration of these compounds is at the Huntley Bridge although their presence was noted at all stations on both the Yellowstone and Big Horn. The Laurel waterworks intake was selected as a control point for comparative analyses since it is above the source of industrial waste and sewage discharge. An unusual combination of circumstances resulted in phenolic pollution above this station during the survey. The intake structure is located well out in the stream (protected by a bridge pier) away from the north river bank. The river bends as it approaches the intake and the current causes the flow from a slough paralleling the stream to cling to the north bank. The slough flows along the south side of oil refinery property. Normally the pollution leaching into the slough flows between the intake and the north bank. Disruption of the flow, as by the construction of a roadway to the intake, diverts the slough discharge around the intake structure. Impounding of slough water and oils, ejected from the pumps in the basement of the raw water pump house, developed severe taste and odors throughout the Laurel water system during the same periods the first carbon filter run was fouled.

BIOLOGICAL FEATURES

The Yellowstone River frequently supports dense bottom algal growths (Table 5) which usually contribute displaced elements that form a considerable portion of the river plankton. In August most bottom growths largely consisted of gelatinous diatom layers, but a green filamentous alga, Cladophora, was more numerous at stations that could be sampled in November. Some ditches carrying wastes to the river also contained attached algal growths.

Table 5. Composition of the microbenthos, August and November

GREEN ALGAE

- Chlamydomonas gr.
- Gloeocystis gigas (Aug. only)
- Gloeocystis vesiculosa (Aug. only)
- Tetraspora lubrica (Aug. only)
- Ulothrix sp. (Nov. only)
- Stigeoclonium sp. (Nov. only)
- Cladophor sp.
- Pediastrum Boryanum (Aug. only)
- Pediastrum duplex (Aug. only)
- Closteriopsis longissima (Aug. only)
- Scenedesmus bijuga
- Scenedesmus dimorphus
- Scenedesmus quadricauda (Nov. only)
- Dictyosphaerium pulchellum (Aug. only)
- Schroederia setigera (Aug. only)
- Coelastrum sphaericum (Aug. only)
- Ankistrodesmus falcatus (Aug. only)
- Actinastrum Hantschii (Aug. only)
- Vaucheria sp. (Nov. only)
- Spirogyra sp. (Nov. only)
- Cosmarium sp.
- Closterium sp. (Aug. only)

EUGLENOPHYTA

- Euglena Ehrenbergii
- Euglena spp.

DIATOMS

- Melosira granulata (Aug. only)
- Melosira sp.
- Stephanodiscus astraea (Aug. only)
- Cyclotella-Stephanodiscus gr.
- Biddulphia laevis (Aug. only)
- Rhizosolenia gr.
- Diatoma vulgare
- Fragilaria spp.
- Synedra gr.
- Cocconeis placentula
- Rhoicosphenia curvata (Nov. only)
- Gyrosigma gr.
- Navicula gr.
- Pinnularia sp.
- Cymbella spp.
- Gomphonema spp.

DIATOMS (Cont'd)

- Amphora sp. (Nov. only)
- Cystopleura spp.
- Rhopalodia gibba (Nov. only)
- Nitzschia sigmoidea
- Nitzschia gr.
- Cymatopleura solea
- Surirella spp.

BLUE GREEN ALGAE

- Merismodpedia punctata (Nov. only)
- Phormidum spp. (included in Oscillatoria gr. in plankton)

FUNGI

- Sphaerotilus sp. (Nov. only)

PROTOZOA

- Centropyxis aculeata (Aug. only)
- Euglypha alveolata
- Lionotus sp. (Nov. only)
- Paramecium putrinum (Nov. only)
- Frontonia sp. (Aug. only)

ROTIFERS

- Philodina sp.
- Lecane sp. (Nov. only)

NEMATODES

- Nematoda spp.

ANNELIDA

- Naididae
- Tubificidae

Copepoda

- Hartpacticoidea (Aug. only)

Plankton populations in August and November were largely composed of displaced bottom algae, and plankton densities increased at varying distances below waste outfalls in response to nutrients contributed in various waste compounds (Tables 6 and 7). Plankton maximums occurred farther upstream in November, although factors associated with oxidation of wastes would favor closer relationship of algal increases and waste outfalls during warmer weather in August. Floating ice present in November may have modified bottom erosion or interfered with discharge patterns.

Plankton did not attain densities sufficient to impair water quality in 1955; however, much greater concentrations have been noted during previous surveys.

Bottom organisms of the fish food class do not occur in stretches significantly affected by oil refinery wastes (Table 8). The most severe effects of such wastes are evident below Billings. In 1955 bottom fauna was very sparse at all river stations.

CARBON FILTER STUDIES

Cylinders of activated carbon were installed to adsorb organic materials from raw water at the Laurel, Billings, and Forsyth water plants. Analyses of carbon extracts reported by F. N. Middleton (Attachment A") indicated that upon two occasions (once at Billings and once at Forsyth) materials so obtained were capable of inducing an odor in the river water. The Forsyth sample was collected over the period January 19 to February 10, 1956, when sugar beet plants were not operating; and materials producing the odor (chloroform extract) were of a volatile oily nature, probably of petroleum refinery origin. The Billings sample with critical odor potential ratio was collected in November 1955, and its odor producing elements were confined to the alcohol extract. Thus it would appear that two different sources of odoriferous compounds were involved at the two localities.

Materials filtered from 100 gallons of raw sugar beet wastes were highly oxygenated and could not be readily classified into general chemical groupings used for most filter extracts. Carbon filters appear less useful for wastes of this type than for those produced by the oil industry.

Carbon filters could not be used to trace materials responsible for objectionable conditions as no such conditions developed during the survey period.

A complete report of the results of carbon filter studies prepared by the Robert A. Taft Sanitary Engineering Center, U. S. Public Health Service, comprises Attachment "A following page 18.

Table 6. Composition of phytoplankton groups

Chlamydomonas gr.

- Chlamydomonas sp.
- Carteria sp.

Gloeocystis spp.

- Gloeocystis gigas
- Gloeocystis vesiculosa

Cyclotella-Stephanodiscus gr.

- Cyclotella bodanica
- Stephanodiscus astraea minutula

Rhizosolenia gr.

- Rhizosolenia
- Nitzschia sp.

Fragiloria spp.

- Diatoma anceps
- Fragiloria spp.

Synedra gr.

- Synedra ulna
- Synedra ulna var. amphirhynchus
- Synedra ulna var. oxyrhynchus
- Synedra ulna var. Ramesi
- Synedra ulna var. aequalis

Gyrosigma gr.

- Pleurosigma delicatulum
- Gyrosigma sp.

Navicula gr.

- Synedra Vaucheriae
- Navicula lanceolata
- Navicula scutum
- Navicula cuspidata var. ambigua
- Navicula radiosa
- Navicula pupula
- Coloneis amphisbaena
- Nitzschia dissipata

Cymbella spp.

- Cymbella affinis
- Cymbella prostrata
- Cymbella pusilla
- Cymbella tumida
- Cymbella turgida
- Cymbella parva
- Cymbella lanceolata
- Cymbella aspera

Gomphonema spp.

- Gomphonema olivaceum
- Gomphonema lanceolatum
- Gomphonema sp.

Cystopleura spp.

- Cystopleura intermedia
- Cystopleura sorex

Nitzschia gr.

- Nitzschia sigmoidea
- Nitzschia spectabiles

Surirella spp.

- Surirella ovata
- Surirella ovalis

Oscillatoria gr.

- Oscillatoria spp.
- Phormidium spp.

Table 7. Yellowstone River Study - Individual Plankton Analyses - August and November 1955

	Y. 366 Elev. 3260 Yellowstone R. above Laurel		Y. 364 Elev. 3240 Yellowstone R. 1 mi. below Laurel	Y. 363.7 C.F. 0.3 Elev. 3230 Clarks Fork Near Mouth		Y. 363 Elev. 3210 Yellowstone R. 3 mi. below Laurel	Y. 349 Elev. 3100 Yellowstone R. Above Billings	Y. 346 Elev. 3071 Yellowsto. R. Below Yegen Drain	Y. 345.8 Elev. 3070 Yellowstone R. U.S. Hwy. 87 Crossing Billings
	8/25	11/9	11/10	8/25	11/9	11/10	8/25	11/7	11/10
PHYTOPLANKTON									
GREEN ALGAE									
Chlamydomonas gr.[3]							1		
Coccomonas[1]									
Gloeocystis spp.[3]									
Tetraspora sp.[3]									
Sphaerocystis schroeteri[1]									
Pediastrum duplex[3]									
Pediastrum boryanum[3]		1							
Coelastrum sphaericum[3]									
Dictyosphaerium pulchellum[3]									
Ankistrodesmus falcatus[3]									
Scenedesmus bijuga[3]									
Scenedesmus dimorphus[3]									
Scenedesmus quadricauda[3]									
Schroederia setigera[3]				5					
Oocystis sp.[1]	1								
Closteriopsis longissima[3]									
Actinastrum Hantzschii[3]									
Crucigenia rectangularis[1]									
Closterium sp.[3]									
Cosmarium sp.[3]	6						6		
EUGLENOPHYTA									
Euglena spp.[3]			51		1				
Trachelomonas sp.[1]							1		
DINOPHYCEAE									
Elearodinium sp.[1]									
DIATOMS									
Melosira granulata[3]	1								
Melosira granulata angustissima[1]	2	2							
Cyclotella-Stephanodiscus gr.[3]	8			24		1	14	2	
Stephanodiscus astraea[3]	7								
Biddulphia laevis[3]									
Rhizosolenia gr.[3]	6	2	1	173	2	11	4		17
Fragilaria crotonensis[1]							4		
Fragilaria spp.[3]									
Diatoma vulgare[3]	1	4	97		43	468		9	183
Rhoicosphenia curvata[3]									
Synedra gr.[3]		47	97	11	304	144		25	130
Asterionella formosa[1]									
Tabellaria flocculosa[3]			2	4		1	14		
Gyrosigma gr.[3]					42	1	2		
Navicula gr.[3]	43	17	48	208	127	47	132	8	52
Pinnularia sp.[3]									
Amphora ovalis[3]						4			4
Amphora veneta[3]									
Gomphonema spp.[3]	3	10	16	14	8	13	13		20
Cymbella spp.[3]		11	27	14	14	37	10		14
Cymatopleura spp.[3]	90	20	31			5	26		
Rhopalodia gibba[3]									
Nitzschia gr.[3]	13			18			15		
Surirella spp.[3]									
BLUE-GREEN ALGAE									
Gomphosphaeria aponina[1]									
Dactylococcopsis sp.[1]									
Oscillatoria gr.[3]			106						
Anabaena sp.[1]									
Aphanizomenon flos-aquae[1]									
ZOOPLANKTON									
PROTOZOA									
Paramecium putrinum[3]			1					25	
Litonotus sp.[3]									
Strombilidium sp.[1]									
Vorticella campanula[3]									
ROTIFERA									
Lecane lunata[3]					1				
Mytilina ventralis[1]									
NEMATODA									
Nematoda sp.[3]									
TOTAL	194	116	477	531	512	712	247	69	420

1 = Occurred in plankton only.
3 = Occurred in plankton and benthos.

Table 7. Yellowstone River Study - Individual Plankton Analyses - August and November 1955--Continued 14 b

	Y. 344 Elev. 3060 Yellowstone R. Below Carter Refinery Outlet	Y. 334.7 Elev. 3000 Yellowstone R. Near Huntley		Y. 264.6 Elev. 2710 Yellowstone R. Near Custer		Y. 219.4 B.M. 40.5 Elev. 2680 Big Horn R. Above Hardin		Y. 219.4, B.M. 40 L.B.M. 1 Elev. 2690 Little Big Horn R. Near Mouth	Y.219.4 B.M. 2 Elev. 2680 Big Horn R. Near Big Horn		Y. 258.7 Elev. 2630 Yellowstone R. Near Myers	
	11/6	8/25	11/10	8/25	11/11	8/26	11/11	11/11	8/25	11/11	8/25	11/12
PHYTOPLANKTON												
GREEN ALGAE												
Chlamydomonas gr.[3]				43				3				
Coccomonas[1]									2			
Gloeocystis spp.[3]		1		1		12				4	12	
Tetraspora sp.[3]					193							
Sphaerocystis schroeteri[1]												
Pediastrum duplex[3]												
Pediastrum boryanum[3]												
Coelastrum sphaericum[3]												
Dictyosphaerium pulchellum[3]												
Ankistrodesmus falcatus[3]												
Scenedesmus bijuga[3]						2						
Scenedesmus dimorphus[3]				1								
Scenedesmus quadricauda[3]		2		4						1		
Schroederia setigera[3]				1								
Oocystis sp.[1]												
Closteriopsis longissima[3]									6		2	
Actinastrum Hantzschii[3]											4	
Crucigenia rectangularis[1]				1		2						
Closterium sp.[3]							1					
Cosmarium sp.[3]		17		17			1				1	
EUGLENOPHYTA												
Euglena spp.[3]		2		4	284							
Trachelomonas sp.[1]												
DINOPHYCEAE												
Fleurodinium sp.[1]												
DIATOMS												
Melosira granulata[3]	1						3					1
Melosira granulata angustissima[1]										1		
Cyclotella-Stephanodiscus gr.[3]		12		188		6		1	4	1	51	2
Stephanodiscus astraea[3]		2					6			8	2	
Biddulphia laevis[3]												
Rhizosolenia gr.[3]	1	10	4	28	1	43	7		54	6	80	4
Fragilaria crotonensis[1]		3		1			1		2	2	1	
Fragilaria spp.[3]							2					2
Diatoma vulgare[3]	88	16	92	1	134		40			3		103
Rhoicosphenia curvata[3]	1											
Synedra gr.[3]	111		137		73		25	6		12		132
Asterionella formosa[1]										1		2
Cocconeis placentula[3]		6	4	6			4			2		2
Gyrosigma gr.[3]	1		7	13	4		2			8	9	2
Navicula gr.[3]	59	172	67	50	69	58	182	4	22	145	53	234
Pinnularia sp.[3]			2									
Amphora veneta[3]	2											
Gomphonema spp.[3]		10	10		4		8			3		1
Cymbella spp.[3]	6	11	27	4	20		2	2			2	10
Cymatopleura spp.[3]	2	42	14	2			1	1			4	
Rhopalodia gibba[3]			2					1				
Nitzschia gr.[3]		29		14		16			5		88	
Surirella spp.[3]										4		
BLUE-GREEN ALGAE												
Gomphosphaeria aponina[1]												
Dactylococcopsis sp.[1]												
Oscillatoria gr.[3]		1	1		1				4			16
Anabaena sp.[1]				1								
Aphanizomenon flos-aquae[1]												
ZOOPLANKTON												
PROTOZOA												
Paramecium putrinum[3]												
Lionotus sp.[3]					1							
Strombilidium sp.[1]		2		2								
Vorticella campanula[3]					2							
ROTIFERS												
Lecane lunata[3]												
Mytilina ventralis[3]					1							
NEMATODA												
Nematoda sp.[3]												2
TOTAL	271	138	367	382	757	137	285	18	99	201	312	513

1 - Occurred in plankton only.
3 - Occurred in plankton and benthos.

Table 7. Yellowstone River Study - Individual Plankton Analyses - August and November 1955--Continued 14C

	Y. 230.8 Elev. 2510 Yellowstone R. at Forsyth		Y. 182.8 Elev. 2130 Yellowstone R. At Ft. Keough Above Miles City		Y. 181.5 T. 0.5 Elev. 2320 Tongue R. Near Mouth	Y. 134.5 Elev. 2170 Yellowstone R. At Terry	Y. 97.1 Elev. 2030 Yellowstone R. At Glendive		Y. 30.7 Elev. 1860 Yellowstone R. Above Sidney		Y. 8.9 Elev. 1870 Yellowstone R. Near Cartwright B.P. Hwy 23 Crossing	
	8/25	11/12	8/26	11/13	11/13	11/13	8/26	11/13	8/26	11/13	8/26	11/14
PHYTOPLANKTON												
GREEN ALGAE												
Chlamydomonas gr.[2]									1			
Coccomonas[1]	1						2					
Glococystis spp.[2]	73		67		3		12		52		88	
Tetraspora sp.[2]												
Sphaerocystis schroeteri[1]	4											
Pediastrum duplex[2]			3				1		4		2	
Pediastrum boryanum[2]												
Coelastrum sphaericum[2]	5		12									
Dictyosphaerium pulchellum[2]												
Ankistrodesmus falcatus[2]									10		2	
Scenedesmus bijuga[2]	3			1					2			
Scenedesmus dimorphus[2]	2		6						18		23	
Scenedesmus quadricauda[2]	2		1						2		6	
Schroederia setigera[2]	8		4								2	
Oocystis sp.[1]									8		4	
Closteriopsis longissima[2]	8		2									
Actinastrum Hantzschii[2]			9						3		12	
Crucigenia rectangularis[1]									15		24	
Closterium sp.[2]			1									
Cosmarium sp.[2]	1		1								1	
EUGLENOPHYTA									2			
Euglena spp.[2]												
Trachelomonas sp.[1]									9		3	2
DINOPHYCEAE											2	
Fleurodinium sp.[1]												
DIATOMS							2					
Melosira granulata[2]												
Melosira granulata angustissima[1]	1	1	8						1		4	
Cyclotella-Stephanodiscus gr.[2]	136	5	196	1			6		92		41	1
Stephanodiscus astraea[2]	1		4			8		2		2	5	
Middulphia laevis[2]				7								
Rhizosolenia gr.[2]	244		209	3	6	4	5		220	39	137	4
Fragilaria crotonensis[1]	1		6			6					1	
Fragilaria spp.[2]								2		3		
Diatoma vulgare[2]	2	28		20		31		14		4		
Rhoicosphenia curvata[2]		1		4		4						
Synedra gr.[2]		26	3	57		168		232		88		108
Asterionella formosa[1]		2	1						1	1		
Cocconeis placentula[2]												
Gyrosigma gr.[2]	8	3		1			5	2	16		8	
Navicula gr.[2]	20	80	10	54	40	73	4	53		6	6	5
Pinnularia sp.[2]												
Amphora ovata[2]												
Gomphonema spp.[2]						1						
Cymbella spp.[2]				2								
Cystopleura spp.[2]		2				5						
Rhopalodia gibba[2]						2						
Nitzschia gr.[2]	2								77		16	
Surirella spp.[2]		4		2								
BLUE-GREEN ALGAE												
Gomphosphaeria aponina[1]			4									
Dactylococcopsis sp.[1]	5		12				4				24	
Oscillatoria gr.[2]				4				2				
Anabaena sp.[1]			1									
Aphanizomenon flos-aquae[1]									3		16	
ZOOPLANKTON												
PROTOZOA												
Paramecium putrinum[2]												
Lieostos sp.[2]												
Strombilidium sp.[1]												
Vorticella campanula[2]											5	
ROTIFERS												
Lecane lunata[2]												
Mytilina ventralis[1]												
NEMATODA												
Nematoda sp.[2]												
TOTAL	527	295	560	176	49	303	42	305	538	143	432	120

1 - Occurred in plankton only.
2 - Occurred in plankton and benthos.

Table 8. Yellowstone River Study - Relative abundance of various benthic organisms

	Yellowstone			Yellowstone				
	Above Laurel	1 mile below Laurel	Clarks Fork	3 miles below Laurel	Above Billings	Below Yegens Ditch	at Huntley	at Custer
Annelid Worms								
Leeches			Rare 11					
Tubificidae(sludge worms)	Rare 11	Abundant	Rare 11					
Snails								
Phyra sp.			Rare 11	Rare 11				Rare 11
Insects								
Stone fly nymphs								
Claasenia sp.	Common 11							
Isogenus sp.	Rare 11							
Mayfly nymphs								
Heptagenia marginalis	Rare 8							
Habrophlebia sp.					Rare 8			
Choroterpes sp.			Rare 8					
Cloeon	Rare 11							
Ameletus sp.	Common 11							
Dragonfly nymphs								
Gomphus sp.								
Damselfly nymphs								
Argia sp.								
Dipterous Flies								
Chironolmidae sp.(midges)	Rare 11		Rare 11					
Atherix sp.(snipe fly)	Rare 11							
Caddis Fly Larvae								
Cheumatopsyche sp.								

NO THOROUGH GANISMS

11 - November, 1955
8 - August, 1955

Table 8. Yellowstone River Study - Relative abundance of various benthic organisms (continued)

	Big Horn at Hardin	Little Big Horn at Hardin	Yellowstone at Myers	Yellowstone at Miles City	Yellowstone at Glendive	Yellowstone at Sidney
Annelid Worms						
Leeches						
Tubificidae (sludge worms)						
Snails						
Phyra sp.						
Insects						
Stone fly numphs						
Claasenia sp.						
Isogenus sp.						
Mayfly nymphs						
Heptagenia marginalis						
Habrophlebia sp.					Rare 8	
Choroterpes sp.				Rare 8		Rare 8
Cloeon		Rare 11				
Ameletus sp.						
Dragonfly nymphs						
Gomphus sp.	Rare 11	Rare 11				
Damselfly nymphs						
Argia sp.			Rare 8			
Dipterous Flies						
Chironomidae sp. (midges)						
Atherix sp. (snipe fly)						
Caddis Fly Larvae						
Cheumatopsyche sp.		Rare 11				

11 - November, 1955
8 - August, 1955

DISCUSSION

The majority of tastes and odors occurring in surface water supplies originates either in wastes discharged to watercourses or in algal or fungus growths. Algal increases to nuisance levels are induced by nutrients contained in waste discharges, or certain wastes kill off an innocuous algal population and produce decaying vegetation to increase the difficulty of water treatment.

In the Yellowstone River water quality impairment may result from any of the above actions. Pollutants, especially those contributed by the oil industry, may reach sufficient concentration to produce unpalatable water when an increase in certain components (mainly phenols) coincides with low water temperature and flow restrictions imposed by floating ice. The onset of colder weather, materially decreasing the rate of exertion of oxygen demand and increasing the time element in the destruction of phenols, will permit longer reaches of the streams to be affected by a given concentration of phenols. The impact of the beet sugar industry with its tremendous organic load also occurs during this season. Synergistic action of this increased organic load in the presence of phenolic compounds must be given consideration. When added to varying concentrations of phenolic wastes, organic wastes may establish an intermittent or cyclic occurrence of objectionable tastes and odors that occur only when the phenol content is above a critical level. Actual operation of the individual phenol producing industries makes the picture even more complex. Discharge of larger quantities of phenols at times of maximum production, spills (accidental or otherwise), and similar instances would develop sudden impacts on the stream.

Oils, either separable or the so-called soluble oils, when discharged to the streams, may intensify tastes and odors. Research to date on the biological oxidation of motor oils indicates: persistence of the oil in water; inhibition of the oxidation of other wastes in the water; temperature has a pronounced effect; and that extracts of oxidized motor oil in research systems were characterized by increased odor factors. If these results hold true for crudes and other oils discharged to river waters, waste oils from producing fields or processing plants will add to taste and odor problems at downstream waterworks.

The periods of "turnaround" in the oil refineries may contribute wastes that impart tastes and odors to the river water or upset the biological balance therein. A visit to one refinery during the "turnaround" period revealed that the effluent of the gravity oil water separator was highly discolored by solids, and officials indicated that it appeared to be much worse than during normal operation.

The slough below the Laurel sewage treatment plant and industrial outlets can also contribute to the over-all problem. When cut off from upstream flow, the slough may accumulate concentrations of oils, phenols, and other taste imparting compounds that are later flushed out by either a rise or a fall in the river.

Plankton algal densities approximating nuisance levels were observed in the lower Yellowstone in August 1952. Algal increases in response to nutrients contained in waste discharges have occurred, and possibilities exist for rapid decimation of seasonally luxuriant benthic growths.

As all surveys have been conducted during periods of little or no taste and odor, it is hardly possible to name the most responsible factor. Also, since it is difficult to differentiate among previous tastes and odors from descriptions of local personnel, the possibility exists that causative agents may vary, with algae producing a problem at one time and industrial wastes at another. The intermittent nature of taste and odor problems suggests that definite combinations of circumstances are required to produce problems arising from any source.

Elimination of benthic fauna in downstream reaches adjacent to oil refinery outfalls and algal stimulation were noted in each of the three periods. This demonstrates that river life and water quality are continually degraded by industrial wastes. Unusual conditions, either in the stream or in the composition and quantity of discharged wastes, that permit greater direct or indirect pollutional influences upon water quality are believed to cause troublesome taste and odor occurrences. Waste discharges pose a major factor in this respect; and, as long as they enter the river in their present form and quantity, taste and odor problems may be expected at frequent intervals. Natural algal blooms are not expected to cause taste and odor problems in the Yellowstone River, but algal stimulation by waste discharges may bring plankton densities to the nuisance level upon frequent occasions.

ATTACHMENT "A"

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YELLOWSTONE RIVER STUDY

ORGANIC CONTAMINANTS RECOVERED BY THE CARBON FILTER TECHNIQUE

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SUMMARY

The objective of this survey was to determine causes of periodic taste and odor in drinking waters using the Yellowstone River as a source of supply. Since serious taste and odor problems did not develop during the survey period, it was not possible to attempt the tracing of the materials which may be responsible for the objectionable conditions previously encountered. Partial analysis was made of materials recovered from carbon filters which were operated at Laurel, Billings, and Forsyth, Montana. An additional filter was operated on the waste effluent from the Great Western Sugar Company at Billings. These data show: (1) the relative quantities of recoverable organics at the various locations (2) the odor producing potential of the organic content and (3) something of the chemical nature of the organic materials in the water.

Total chloroform and alcohol extractable materials varied in concentration from 135 p.p.b. at Laurel to 578 p.p.b. at Forsyth. The recovered materials were detectable by odor tests at concentrations ranging from 40 p.p.b. to 512 p.p.b. Based on the concentrations of materials found and the concentration of extracts detectable by odor only two instances were found when odor would have been probable in the water. Chemical breakdown of the materials revealed that neutral components were most abundant followed by water soluble materials and acidic materials. Samples from the various locations were not significantly different except for the last sample from Forsyth which was strikingly different. The last sample from Forsyth (Jan. Feb. 1956) contained a significant quantity of light hydrocarbons which are probably of petroleum refinery origin. No effects of sugar plant wastes were obvious from the carbon filter study.

A. BACKGROUND

In connection with periodic tastes and odors in the city water supply of Forsyth, Montana and other cities on the Yellowstone River, the Montana Health Department through Glen Hopkins, Assistant Regional Engineer, DHEW, Region VI, requested that a study be made of contributing causes to taste and odor difficulties using the carbon filter sampling technique. Accordingly, carbon filters were shipped to Montana in September, 1955. Tastes and odors have usually developed in the fall months and have coincided with the operation of sugar refining plants in the area. However, the problem does not always occur.

Sampling Locations:

1. Laurel, Montana - finished water.

This water supply served as the control point since its location on the Yellowstone is above the principal sources of pollution which are petroleum refineries at Laurel and Billings, sugar plants at Billings and Hardin on the Big Horn River and sewage effluents.

2. Billings, Montana - finished water.

This city is about fourteen miles downstream from Laurel. Pollution from petroleum refinery operations at Laurel may reach Billings.

3. Forsyth, Montana - finished water

Forsyth is approximately 115 miles downstream from Billings. Principal effluents that may affect the water supply are the petroleum refineries, one at Laurel and two at Billings and the sugar plants - one at Billings and one at Hardin on the Big Horn River. The Big Horn flows into the Yellowstone approximately 50 miles above Forsyth.

4. For purposes of exploring the usefulness of the carbon technique on sugar plant effluents, a trial sample of effluent from the Great Western Sugar Company at Billings was passed through the filter and analyzed.

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LABORATORY RESULTS

Since the carbon filter is not a standard technique, a brief explanation should help the reader in understanding the results. Several thousand gallons of the water to be tested are passed through a cylinder of active carbon at a rate of 1/4 to 1/2 gallon per minute. The carbon is dried and extracted with chloroform followed by extraction with alcohol to recover the organic materials which had been adsorbed from the water. Removal of the solvent by distillation leaves a complex residue which is then examined by chemical means. It has been found that the materials recovered by the chloroform are usually most significant as taste and odor compounds. The alcohol extraction will partially recover highly colored materials and such materials as synthetic detergents if they are present. The chloroform extractable materials are separated into broad chemical groups based on their solubility characteristics. These groups are: water solubles, amines (or bases), neutrals, weak acids (includes phenols), strong acids, and ether insolubles. Additional separation of the neutral materials by chromatographic techniques is accomplished. Taste and odor tests, infrared spectra or other determinations are made as necessary. Further interpretation of the findings will appear in appropriate sections of this report.

Table 1 shows the times of sampling, the amount of water filtered and the total amounts of organic materials recovered. The recovery of chloroform extractables at Laurel and Billings was quite low (25 to 44 p.p.b.) and compares with quantities recovered from waters where very little organic pollution exists. For example, Cincinnati tap water (source Ohio River) contains two to four times the concentration of materials found at Laurel and Billings. The organic content at Forsyth was

significantly higher, reaching a concentration of 306 p.p.b. in January and February. Extraction of the carbon with alcohol, following the chloroform extraction, yielded additional organic materials ranging from 69 to 272 p.p.b.

To determine the potential odor intensity and characteristics of the recovered organic materials weighed portions of the chloroform and alcohol extracts were dissolved in odor-free water and serial dilutions of the material were presented to a panel of observers. The geometric mean of the threshold odor observations of the individuals was recorded as the threshold of the sample. Table 2 lists these results.

It is of interest to determine whether the recovered materials would be likely to produce odor in water. The relationship of the concentration of material recovered to the minimum quantity detectable by odor tests (the threshold) gives an indication of the odor potential of the materials. This relationship can be expressed by:

$$\text{Odor Potential Ratio, \%} = \frac{\text{p.p.b. of Material} \times 100}{\text{Threshold Concentration in p.p.b.}}$$

If the OPR is 100 per cent or more, threshold levels are exceeded and odorous water would be likely to result. Certainly at levels of 500 per cent or over, many people would be likely to complain. Table 3 shows the OPR for the chloroform and alcohol extracts. Examination of the odor potential ratios indicates only two instances (sample 537 alcohol extract and sample 551 chloroform extract) when the recovered materials were sufficiently odorous to indicate possible odor in the water. This is in accord with observed conditions during the survey as very little odor was observed. Because of the lack of development of odorous conditions,

detailed odor studies of the various sub-groups of materials were not made. Since phenols were measured directly on the survey, they were not tested for in the extracts.

The results of chemical separation of the chloroform extractable materials recovered appear in Table 4. These separations are based on the differences in solubility characteristics of organic chemicals and reveal, at least, gross characteristics of the materials.

Neutral compounds were most abundant of the groups recovered. Materials which may be found in this group include hydrocarbons, and such oxygenated compounds as aldehydes, ketones, ethers, and esters. The materials are usually highly odorous. Considering Laurel as the control, the only significant differences in the quantity of neutrals were on samples 537 (Billings) and 551 (Forsyth), represented by an increase. Upon chromatographing the neutral components into aliphatic, aromatic and oxygenated fractions (see Table 4) results were comparable with oxygenated substances accounting for the major portion of the materials. Aromatics in sample 546 (Forsyth) were significantly higher than those at Laurel. These data may indicate refinery materials, but this was not confirmed. Sample 551 from Forsyth during the period of January and February contained highly volatile materials of an oily nature which were not adaptable to chromatographic separation. Infrared tests indicated aromatic and olefinic materials which may be of refinery origin. The hydrocarbons recovered were much lower boiling than those we have previously encountered from petroleum refineries. It may be that cold water conditions preserved the materials.

The strong acid fractions of two samples from Forsyth were significantly higher than those from Laurel and Billings. At the same time, the neutrals were lower. Sample 554 from Forsyth showed high neutrals and low amounts of strong acids. This sample was strikingly different from all of the others. It may be surmised that biochemical oxidation was at a low level during this period since the low values obtained in the acid fractions and water solubles indicate lack of oxidized products.

Weak acids include those materials which are released from solution by carbon dioxide and include simple phenols if present. The percentage of weak acids is not, however, a guide to the amount of phenol present since many materials may fall within this group. Acidic fractions, both strong and weak are usually rather odorous.

Amines or organic bases are usually the least abundant of the groups recovered. In the samples from the Yellowstone, no significance is attached to the quantities found.

Water solubles refer to those materials which favor the water phase in a water-ether mixture. The materials are generally not significant from the taste and odor standpoint, although they constitute a substantial portion of the total organics.

A summary of the findings by cities follows:

Laurel-Lab No. 536 - Period 9-27-55 to 11-18.

The chloroform extract was a yellow brown wax of mainty odor and the alcohol extract was a dark brown viscuous liquid having a caramel odor. A slight layer of oil was observed on the chloroform extract. This did not appear to be a waste component; it may have been contamination from a pump lubricant. The components of the extract appeared to

be natural materials. The chloroform extractable materials and the alcohol soluble materials were about equal as odor contributors.

Billings-Lab No. 529 - Period 9-27-55 to 11-18.

537 - Period November.

Total organics were: No. 529-208 p.p.b. and No. 537-141 p.p.b. These raw extracts were similar to those obtained at Laurel. The thresholds of 430 and 40 on the chloroform extracts were significantly different. Sample 537 was unusual in that the odor contribution of the alcohol extract exceeded that of the chloroform extract. Again, as at Laurel, the natural materials and the oxidation products of these materials constituted the bulk of the sample. Refinery pollution was not evident.

Forsyth-Lab No. 528 - Period 9-27-55 to 10-4.

546 - Period 11-15-55 to 1-11-56.

551 - Period 1-19-56 to 2-10-56.

The total organics recovered showed increasing amounts (154, 253, and 578 p.p.b.). However, odor levels of the recovered extracts were not extraordinarily high although with the quantities of materials recovered on sample 551, odor would almost certainly be present. The chloroform extract of sample 551 was strikingly different from the other samples. A light yellow, somewhat volatile oil made up the bulk of the sample. Oxygenated materials were present in low amounts. The small quantity of material prevented extensive analytical tests on the materials. Infrared evidence indicates the material to be aromatic and olefinic hydrocarbons. They may be of refinery origin but certain of the usual refinery waste characteristics found in other waters we have examined are lacking.

Sample 528 was collected prior to the operation of the sugar refineries. No. 546 was taken during the campaign and No. 551 was representative of the period after the plants closed. It is difficult to say from these data what the effect of sugar refinery waste was on the stream. One may conjecture that following the campaign, normal biological oxidation was interfered with hence the unusual sample (No. 551) at Forsyth. It is also possible that spill or unusual happening caused the difference noted.

Effluent from Great Western Sugar Plant - Billings, Montana

One hundred gallons of plant effluent was passed through a carbon filter on November 12, 1955. The dried carbon was extracted successively with ether, chloroform and alcohol. Ether and chloroform extracts were separated into chemical groups. Table 5 summarizes these results and the results of odor tests on certain of the materials. The alcohol extract accounts for the bulk of the organic content and is the principal odor contributor. This extract had a fermentive or wine-like characteristic compared with a strong acidic odor in the ether extract and a septic or stale odor in the chloroform extract. The bulk of the material recovered was composed of highly oxygenated materials and no definitive chemical characterization was practicable. While the carbon filter may have some usefulness on effluents such as those from the sugar plants, it serves best on materials not originating from biological processes.

Respectfully submitted,

F. M. Middleton

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Participating in this study were;

Mr. Rice H. Burttschell performed the bulk of the analyses.

Mr. Henry Pettit performed extractions and ran infrared spectra.

Dr. A. A. Rosen assisted in interpretation of data and report writing.

All work was in the Chemistry & Physics group under Mr. M. F. Ettinger.

Table I

RECOVERY OF ORGANIC MATERIALS FROM CARBON FILTER

Source	Laurel	Billings		Forsyth		
Loc. No.	536	529	537	528	546	551
Dates of Operation	9-27-55 to 11-18	9-27-55 to 10-5		9-27-55 to 10-4	10-15-55 to 1-11-56	1-19-56 to 3-10-56
Gallons Filtered	7,777	5,000	5,895	5,010	5,564	3,019
Quantities Recovered, Grams						
Chloroform	0.76	0.83	0.55	2.68	1.73(2)	3.49
Alcohol	3.2	3.1	2.4	4.78	3.57	
TOC(1) Chloroform	26	44	25	93	83	306
Alcohol	169	164	120	89	170	272
TOC	195	208	144	182	253	578

(2) P.p.b. = parts per billion.

(2) Due to a laboratory spill, this figure may be slightly in error.

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Table 8

ODOR DATA

Source	Laurel	Billings		Forsyth		
Lab No.	535	529	537	528	546	551
Extract		Threshold Odor Concentration parts per billion				
Chloroform	80	439	[illegible]	395	390	197
Alcohol	256	256	40	395	256	512

Table 3

ODOR POTENTIAL RATIOS

Source	Laurel	Billings		Forsyth		
Lab No.	536	529	537	528	546	551
Odor Potential Ratio Per Cent of Extracts(1)						
Chloroform	33	10	63	28	28	286
Alcohol	41	60	250	23	67	55

(1) $\frac{\text{Parts per Billion} \times 100}{\text{Threshold Concentration, p.p.b.}}$

Table 4

CHEMICAL GROUPS SEPARATED FROM CHLOROFORM EXTRACT

Source	Laurel	Billings		Forsyth		
Lab No.	536	529	537	528	546	551
Groups	PERCENT OF TOTAL					
Water Soluble	19.7	17.8	16.2	25.0	34.8	13.2
Amines	2.8	3.7	1.0	0.8	1.5	1.1
Neutrals	46.1	40.2	61.4	31.9	33.3	79.0
Weak Acids	7.5	7.7	12.3	5.6	4.5	2.1
Strong Acids	14.2	11.7	9.1	21.5	21.3	3.7
Ether insolubles	9.8	18.8	Trace	12.7	4.5	0.0
Neutral Fractions	PERCENT OF NEUTRAL GROUP					
Aliphatic	10.3	3.1	10.7	3.7	6.2	-
Aromatic	14.7	18.4	16.0	8.5	23.4	-
Oxy	75.0	78.5	73.3	87.8	70.2	-

Table 9

COLLECTION AND CHEMICAL DATA - EFFLUENT FROM GREAT WESTERN SUGAR COMPANY - BILLINGS, MONTANA

Source	Plant Effluent	Threshold Odor p.p.b.	Relative Odor(1) Contribution
Gallons filtered	100		
Extract recovered grams			
Ether	0.30	64	75
Chloroform	0.52	200	42
Alcohol	5.40	410	2120
ppm			
Ether	790		
Chloroform	1370		
Alcohol	14200		

Grams recovered, %	Ether	Chloroform
Water soluble	9.8	12.0
Amines	2.6	4.4
Neutrals	67.5	64.9
Weak acids	11.3	7.1
Strong acids	9.9	11.6
Ether insolubles	-	-
Neutral fraction		
Aliphatic	46.4	10.6
Aromatic	11.3	11.8
Oxy	39.3	77.6

(1) $\frac{\text{gm of material} \times 1000}{\text{Threshold Concentration}}$ = . . .